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13. ABSTRACT

This report documents the Optimization Model developed as part of the Integrated Facilities Requirements Study (IFRS).

In Phase I, two analytic submodels were developed. The first, a Logistics Support Requirements Generator, estimates personnel, aircraft, and fuel requirements for each phase of undergraduate pilot training at the Naval Air Training Command (NATRACOM). The second, a Pacing Facilities Requirements submodel, calculates facility requirements for each phase of training.

The purpose of the Phase II study was to develop a preliminary total systems IFRS management planning tool (including the two submodels developed in Phase I, as well as Base Loading, Facilities Excess/Deficiency, and Total Cost submodels), and automate the model so that it provides quick, accurate, and relevant information for use in the decision-making process. This Static IFRS model has been in continuous operation since March 1970.

The purpose of the Phase III study was to refine the Static IFRS model and to expand the IFRS concept by developing three additional planning tools for use by Navy decision-makers as follows:

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- Dynamic planning tool
- Optimization model
- Fleet Readiness Training Squadron planning tool.

The Dynamic planning tool simulates the undergraduate pilot training program on a weekly basis whereas the Static IFRS assumes an even annual flow of students. The Optimization model has two segments - a PTR Maximizer that calculates the maximum annual pilot training rate (PTR) possible for a given facilities inventory and a MCON Minimizer that calculates the minimum facility cost phase-to-base assignment for a desired PTR. The Fleet Readiness Training (FRT) model provides planning information for the readiness training squadrons and is designed similarly to the Static IFRS model. The Phase III documentation consists of the following four reports:

- The Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 645

- Development of the Automated Dynamic Model for the Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 646

- Development of the Optimization Model for the Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 647

- Development of the Fleet Air Readiness Training Model for the Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 648.

This report documents the Optimization model. Volume I contains a Summary of the two submodels - The PTR Maximizer and The MCON Minimizer. Volume II contains the Detailed Model Formulation, User Instructions and an appendix of the functional relationships.

OPERATIONS RESEARCH, Inc.

SILVER SPRING, MARYLAND

Development of the Optimization Model for the Integrated Facilities Requirements Study (IFRS) Phase III

Volume I - Summary of the Optimization Model

31 March 1971

Prepared under Contract N00025-67-C-0031 (NBy-78672)
for the Naval Facilities Engineering Command
Department of the Navy
Washington, D.C.

FOREWORD

This report documents the Optimization model developed as part of the Integrated Facilities Requirements Study (IFRS). It has been prepared for the Systems Analysis Division of the Office of the Assistant Commander for Facilities Planning (Code 20), Naval Facilities Engineering Command (NAVFAC), Department of the Navy, as part of Contract N00025-67-C-0031 (NBy-78672) awarded to Operations Research, Inc., in June 1970.

In Phase I, two analytic submodels were developed. The first, a Logistics Support Requirements Generator, estimates personnel, aircraft, and fuel requirements for each phase of undergraduate pilot training at the Naval Air Training Command (NATRACOM). The second, a Pacing Facilities Requirements submodel, calculates facility requirements for each phase of training.

The purpose of the Phase II study was to develop a preliminary total systems IFRS management planning tool (including the two submodels developed in Phase I, as well as Base Loading, Facilities Excess/Deficiency, and Total Cost submodels), and automate the model so that it provides quick, accurate, and relevant information for use in the decision-making process. This Static IFRS model has been in continuous operation since March 1970.

The purpose of the Phase III study was to refine the Static IFRS model and to expand the IFRS concept by developing three additional planning tools for use by Navy decision-makers as follows:

- Dynamic planning tool
- Optimization model
- Fleet Readiness Training Squadron planning tool.

The Dynamic planning tool simulates the undergraduate pilot training program on a weekly basis whereas the Static IFRS assumes an even annual flow of students. The Optimization model has two segments—a PTR Maximizer that calculates the maximum annual pilot training rate (PTR) possible for a given facilities inventory and a MCON Minimizer that calculates the minimum facility cost phase-to-base assignment for a desired PTR. The Fleet Readiness Training (FRT) model provides planning information for the readiness training squadrons and is designed similarly to the Static IFRS model. The Phase III documentation consists of the following four reports:

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- Development of the Optimization Model for the Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 647
- Development of the Fleet Air Readiness Training Model for the Integrated Facilities Requirements Study (IFRS) Phase III, ORI TR 648.

This report documents the Optimization model. Volume I contains a summary of the two submodels—the PTR Maximizer and the MCON Minimizer. Volume II contains the detailed model formulation, user instructions and an appendix of the functional relationships.

These IFRS models were developed and programmed by the staff members of the Economic Analysis Division of Operations Research, Inc., under the direction of Dr. William J. Leininger, vice president and division director, and Thomas N. Kyle, program director. The project team members included R. J. Craig, M. C. Fisk, W. Liggett, F. McCoy, R. Messalle, and R. Yockman.

Mr. Dennis Whang of the Systems Analysis Division of Facilities Planning was contract monitor for NAVFAC. In addition, valuable assistance was provided by many other Navy personnel including, in particular, those in the Office of the Staff Civil Engineer and the Training/Plans Division of the Naval Air Training Command, the Aviation Training Division of the Chief of Naval Operations, and in the Systems Analysis Division of NAVFAC. The authors gratefully acknowledge the contributions made by all of these people to the development of the IFRS models.

SUMMARY

This report documents the Optimization model developed as part of the third phase of the Integrated Facilities Requirements Study (IFRS). The objective of this task is to develop a first generation, or prototype, optimization model that provides the decision-maker with information concerning where each undergraduate pilot training phase should be located in order to:

- Maximize the pilot training rate (PTR) for a given facility inventory (i.e., facility stock)
- Minimize the military construction cost (MCON) for a desired PTR.

Two separate submodels were developed to fulfill this objective:

- PTR Maximizer—The purpose of this submodel is to calculate the phase-to-base assignment that provides the maximum possible student output that can be achieved with the existing facility stock at the pilot training bases. This submodel uses linear programming to determine the optimal phase-to-base assignment and is presently operational on a batch processing computer system.
- MCON Minimizer—The purpose of this submodel is to calculate the phase-to-base assignment that provides the minimum facilities investment cost for a given student output. This submodel also uses linear programming and is presently operational on the Navy's UNIVAC 1108 computer.

The development of these two prototype submodels verifies the feasibility of developing optimization models for facilities management purposes. These two submodels provide the facilities manager with a powerful analytical tool that can enhance the decision-making process.

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I. INTRODUCTION

OBJECTIVE

1.1 The objective of this study is to develop a first generation, or prototype, optimization model that provides the decision-maker with information concerning where each undergraduate pilot training phase should be located in order to:

- Maximize the pilot training rate (PTR) for a given facility's inventory (i.e., facility stock), and
- Minimize the military construction cost (MCON) for a desired PTR.

1.2 The development of the Optimization model is within the general scope of the Integrated Facilities Requirements Study (IFRS) and is one of the series of management tools developed under the IFRS study. The primary source of information was the functional relationships and data contained in the Phase II Static IFRS model. Thus the facilities included in the model account for approximately 75% of the replacement value of the eight bases.

STUDY PLAN

1.3 Since very few optimization algorithms of this type have been developed, the first task was to establish the feasibility of developing an optimization algorithm. Initially it was necessary to identify those variables that would be either maximized or minimized. The variable to be maximized is the PTR which can be measured by the student load. The variable to be minimized is cost. Hence, it was necessary to segregate total costs into fixed and variable portions, since the Optimization model can minimize variable cost but cannot affect the fixed costs. Based on the results of the above analysis, the optimization technique was selected and trial runs were made.

STUDY END PRODUCT

1.4 The end product of this effort consists of two separate algorithms—a PTR Maximizer submodel and a MCON Minimizer submodel—and relevant documentation. Both submodels employ the linear programming technique to optimally assign training phases to bases. The PTR Maximizer submodel calculates the phase-to-base assignment that results in the maximum achievable PTR for a given set of facilities and given pilot training program. The MCON Minimizer calculates the phase-to-base assignment that requires the minimum military construction cost (i.e., facilities investment cost) for a desired PTR and pilot training program. The size of the submodels and the length of time required to run them dictate the use of large batch processing computers. Time-sharing computer systems are uneconomical for these large-scale optimization algorithms at the present time.

1.5 The documentation consists of two volumes. This volume provides an overview of the two submodels, and Volume II describes the mathematical formulations and use of the submodels.

SIGNIFICANT CONTRIBUTIONS OF THE OPTIMIZATION MODEL

1.6 Even though the PTR Maximizer and MCON Minimizer submodels are first generation optimization algorithms, they provide the Navy managers with unique tools that can and should be used to determine which phase-to-base assignment provides maximum economic utilization of facilities. They can be especially useful to management when major changes are contemplated in the undergraduate pilot training program. These two submodels provide the Navy managers with an unbiased assessment of where the training phases should be located (based on the factors included in the submodels). However, various types of problems (e.g., operational) may require management to deviate from the optimal phase-to-base assignment. However, it is important to note that the output of the submodels does provide information so that the economic cost of deviating from the optimum can be determined.

Model User

1.7 It is presently anticipated that the Headquarters, Naval Facilities Engineering Command (NAVFAC), will be the primary user of these submodels, since this office is responsible for the overall management of Naval facilities.

Potential Expansion to Other Navy Commands

1.8 Since these prototype models are presently operational, it appears that basically the same linear programming technique can be used to develop optimization models for other Navy commands. However, it is recommended that the desirability of developing models that calculate economically (i.e., based on cost) optimal phase-to-base assignments should be clearly established prior to expanding this management tool to other commands.

II. THE STATIC IFRS MODEL

INTRODUCTION

2.1 As stated previously, the base source of information used in the development of the Optimization model was the Static IFRS model developed by ORI in the Phase II IFRS Study.[1] The Static IFRS model is a management planning tool that incorporates thousands of pilot training planning factors and functional relationships into a series of computer programs on a time-share computer system. The Static IFRS model was developed completely independent of the Optimization model and thus its data files and functional relationships had to be analyzed and converted to the proper format for the Optimization model.

2.2 This section contains a discussion of those features of the pilot training production process that are replicated in the Static IFRS model, the methodology employed, and an analysis of the Static IFRS model.

PILOT TRAINING PRODUCTION SYSTEM

The Pilot Training Process

2.3 The present pilot training program consists of 15 separate but related training phases through which a student must progress until he graduates as either a jet, propeller (prop), or helicopter (helo) pilot. The type of pilot determines the precise phases that a student must complete. The percentage of graduates in the jet, prop, or helo aircraft is termed the MIX. The phase content, the syllabi, and the general operating procedures are called the MODE.

1/ For a complete discussion of the Static IFRS model, see Development of a Preliminary Total Systems Model for the Integrated Facilities Requirements Study (IFRS), Phase II, ORI TR 583, 9 February 1970.

Resources Required by Each Phase

2.4 Each of the training phases requires a certain number of resources—i.e., instructors, administrative officers, enlisted men, aircraft, and fuel. The total amount of each resource required is a function of the PTR, MIX and MODE. Essentially, the total manpower, aircraft and fuel requirements for each phase are independent of the location of the training phase.

Location and Facility Requirements

2.5 The next pertinent factor is that these 15 phases are located at 8 different naval air stations (NASs). The location of each phase (or portion of a phase) at a base is called the phase-to-base assignment. Each NAS has a unique facility inventory (i.e., stock) which is used to support the pilot training phases assigned to that base, tenant activities located at the base, as well as the NAS personnel. The combined size of the tenant activities and training phases located at each NAS determines the total personnel and facility inventory required by each base. No two bases are identical and each base has different amounts of facility stocks that can be used by the men and aircraft in the pilot training program.

STATIC IFRS LOGIC

2.6 The Static IFRS model essentially replicates the present planning methodology of the undergraduate pilot training program. This model consists of the five modules and related data files as shown in Figure 2.1. Each of these modules is briefly discussed in the following paragraphs.

Logistics Support Requirements (LSR) Module

2.7 The purpose of the LSR module is to calculate the total manpower, aircraft, and fuel required to conduct a training phase independent of a specific location. Each phase of training is defined by a series of pilot training planning factors that specify the MODE of training. The decision-maker enters a desired PTR and then the resources required by each phase are calculated.

Base Loading Module

2.8 The Base Loading module converts all phase specific data of the LSR module to base specific data and then calculates the total manpower, aircraft, and fuel requirements for each base (i.e., the sum of training phase, tenant, and NAS requirements). The training phases are assigned to particular NASs by the manager. The model permits the manager to assign one or more phases or parts of a phase to any of the eight bases.

Facilities Requirements Module

2.9 The Facilities Requirements module calculates the quantity of specific permanent facilities required at each base to support the total base population defined above. There are 24 different facility line items included in the model which represent approximately 70% of the replacement value of the eight NASs.

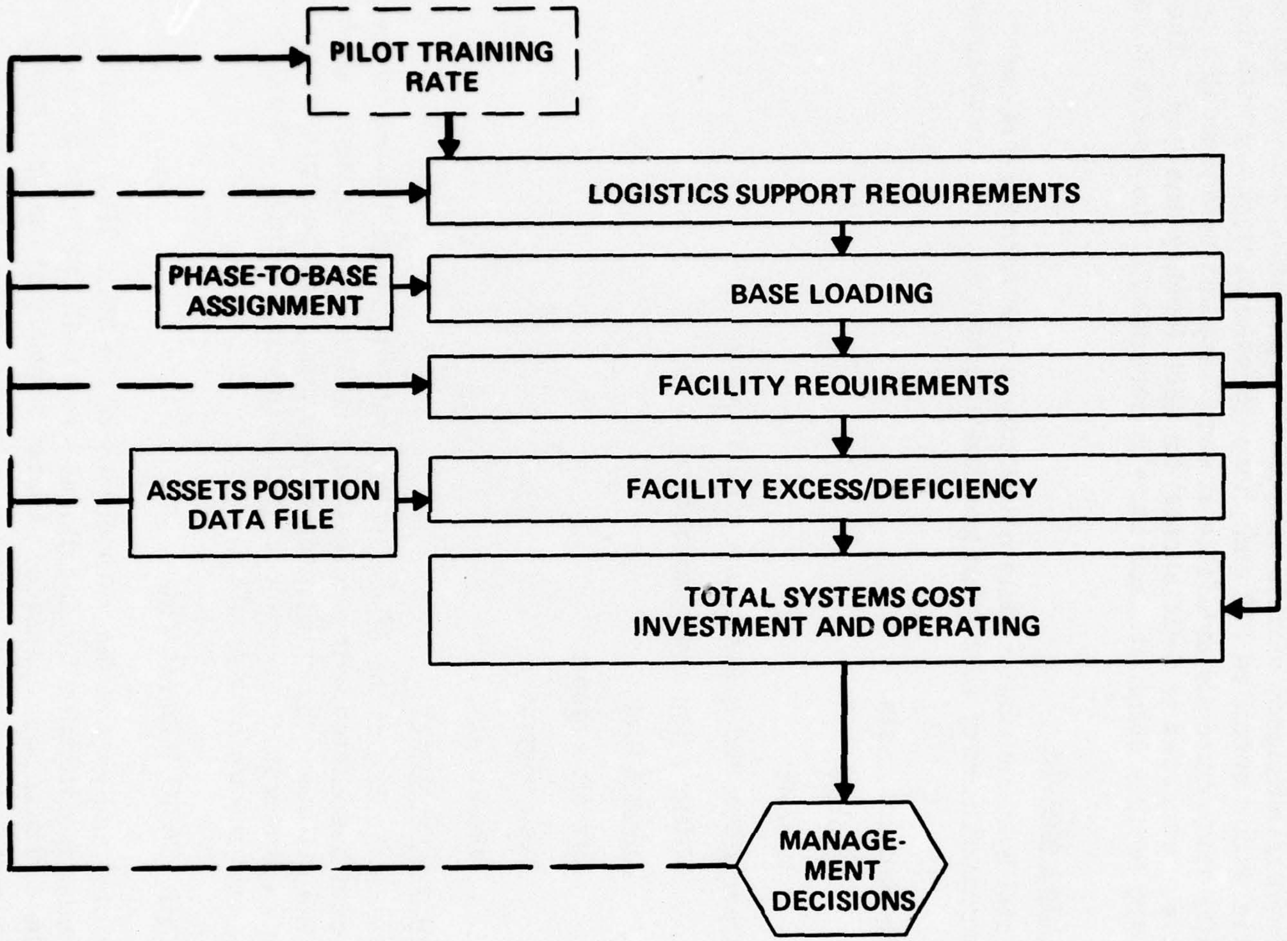

FIGURE 2.4. OVERVIEW OF STATIC IFRS MODEL

The selection of these facility line items was based on their importance to the pilot training mission and their high replacement cost. A list of these facilities, including the category code number and units of measure, appears in Table 2.1.

Excess/Deficiency Module

2.10 The Excess/Deficiency module compares the preceding facility requirements associated with a specified PTR and phase-to-base assignment with the amount of facility stock currently available at each base and then computes net requirements (i.e., excesses or deficiencies) for each facility line item. The amount of existing facility stock at each base is contained in the Assets Position data file.

Total Systems Cost Module

2.11 The Total Systems Cost module calculates the investment and operations and maintenance cost of each pilot training alternative. The cost categories included are:

- Investment costs
  - Facility
  - Aircraft
- Operations and maintenance (O&M) costs
  - Military pay and allowances
  - Aircraft fuel
  - Aircraft support
  - Base support
  - Fixed costs.

Summary of Static IFRS Model

2.12 Thus with the use of the Static IFRS model,[2/] the decision-maker can determine the cost associated with alternative pilot training programs. He can vary the PTR; the syllabus; the percentage of jet, prop, and helo pilots; the phase-to-base assignment; the current facilities inventory, etc., and see how these factors affect the training program.

ANALYSIS OF THE STATIC IFRS MODEL

2.13 A detailed analysis of the methodology of the Static IFRS model was necessary in order to determine the functional forms that had to be considered in selecting the optimization technique. A brief summary of the analysis of each module follows.

2/ Ibid.

TABLE 2.1

LIST OF FACILITY LINE ITEMS INCLUDED IN STATIC IFRS MODEL

IFRS Category Code	Facility Description	Units of Measure
1320	Aircraft parking apron	sq yd
1320	Peripheral taxiways	sq yd
11320	Total parking apron	sq yd
12540	Distribution pipeline	miles
14140	Aircraft operations building	sq ft
17110	Academic building	sq ft
21110	Aircraft maintenance hangar	sq ft
21910	Public working maintenance shop	sq ft
4210	General warehouse	sq ft
4210	Shed space	sq ft
44210	Total general warehouse	sq ft
55010	Dispensary with/without beds	sq ft
61010	Administrative office	sq ft
71110	Family housing (officer and eligible enlisted men)	units
72210	Enlisted men's barracks with/without mess	men
72310	Enlisted men's mess hall	sq ft
72415	BOQs with/without mess	men
74014	Exchange	sq ft
74063	Enlisted men's service club	sq ft
81230	Distribution line (electrical)	ft
84210	Water distribution line (potable)	ft
85110	Roads	miles
85210	Parking areas	sq yd
	Runway lighting	ft
	Taxiways	sq yd
	Ready fuel storage required	gallons
	Runways	sq yd

LSR Module Analysis

2.14 The analysis of functional relationships of the LSR module resulted in the following conclusions. All manpower, aircraft and fuel requirements equations are linear with a zero intercept. The variable that determines the overall size of the pilot training program is the primary input to this module, i.e., the PTR. For a particular training MODE and MIX of graduates, this PTR can be directly translated into the average number of students on board (the student load). Since each training phase has a different syllabus, the amount of manpower, aircraft, and fuel required, as well as the student load, is different for each phase (i.e., no two phases have identical resource requirements). However, for a given PTR, MIX, and MODE, these phase resource requirements can be estimated in a linear relationship as a function of student load.

Base Loading Module Analysis

2.15 The results of the analysis of the functional relationship in the Base Loading module are as follows. The NAS manpower requirements are estimated by linear equations with fixed intercepts as a function of training phase plus tenant population. The tenant population is independent of the pilot training program and is fixed for each base. In the development of these prototype optimization submodels, it was assumed that all eight NASs would be used. Thus the fixed segment of the NAS population is required at each base regardless of the number of training phases or parts thereof assigned to each base. Additionally, the amount of the variable portion of NAS population required by the tenants can be easily determined and remains constant (i.e., as long as the tenant population remains constant). The sum of the variable portion of NAS population required for all 15 training phases is the same regardless of where the phases are located. Thus for a given PTR, MIX, and MODE, the total NAS population (i.e., sum of eight bases) remains constant.

Facilities Requirements Module Analysis

2.16 There are approximately 30 different equations in the Facilities Requirements module and thus those for each facility line item were analyzed separately. The details of these equations appear in Volume II of this report; however, some general comments are appropriate at this time. The equations that are used to estimate the facility line items requirements are either linear or can be closely approximated by linear functions. The facility requirements for a base can also be divided into two segments:

- Facilities required by tenants
- Facilities required by training phases.

2.17 Tenants are unique to each base; therefore the calculation of their facility requirements by line item is straightforward and the amount required is independent of the pilot training program.

2.18 The composition of each training phase is different and thus the facility requirements are different for each phase. Since the student load of each phase is directly related to the desired PTR and MIX, the facility requirement of each phase can be expressed as units of facility required per student. Thus for the 15 training phases and 1 facility line item, there are 15 different values of each facility type required per student. The assumption of continuous linear relationships to estimate facility requirements appears to pose no major problems. However in the case of runways, this assumption may result in fractional runways being identified as a requirement. If a facility's requirements are estimated in step functions, a linear relationship is estimated by regression analysis.

Excess/Deficiency Module Analysis

2.19 The analysis of this module resulted in the identification of many of the constraints to be included in the optimization process. Essentially, the values in the Assets Position data file state the amount of each facility line item presently available. This is the amount to be included in the optimization algorithm to ensure that no unnecessary facilities are built. This module posed no problems to the optimization concept.

Total Systems Cost Module Analysis

2.20 The results of the analysis of this module are manifold. Each of the cost categories is discussed separately.

2.21 The facility investment cost required to build those facilities identified as being deficient includes a size/cost adjustment factor that had to be eliminated in order to use these costs in an optimization algorithm. This size/cost adjustment factor was included in the Static IFRS to reflect economies of scale in constructing different size facilities. Its elimination should have no adverse effect on the output of the optimization algorithm. All other features of the facility investment cost are used with resulting linear equations. Since the per student requirement of each facility line item can be calculated for each phase, the cost of building the per student requirement can also be calculated for each phase and line item.

2.22 Aircraft investment costs are incurred when new aircraft must be procured and are independent of the phase-to-base allocation. Thus those costs need not be included in the optimization algorithm.

2.23 The annual military pay and allowances cost is a direct function of the number of military personnel in the training phases and NASs. Since all eight NASs are utilized and since the NAS manpower is estimated by linear equations, the total amount of this O&M cost category is fixed regardless of the phase-to-base assignment and thus need not be included in the optimization algorithm.

2.24 Similarly, the aircraft fuel and support costs are estimated as a function of flight hours. The amount of flight hours is determined by the PTR, MIX, and MODE and is assumed to be independent of phase location. Thus these costs are excluded.

2.25 The base support costs are essentially costs associated with NAS operations. These costs are estimated by a linear equation with a fixed intercept, and as long as all eight bases are used, this total cost (i.e., sum of eight bases) does not vary for a given PTR, MIX, and MODE. By definition, the fixed costs of the headquarters do not vary.

Static IFRS Analysis Summary

2.26 As a result of this detailed study of the functional relationship in the Static IFRS model, it was determined that:

- Training phase resource requirements are linear and can be expressed in terms of student load.
- NAS manpower requirements are linear and total base population can be identified as being either tenant related or training phase related.
- Facility line item requirements can be expressed in terms of amount required per student for the 15 different training phases independent of base. (Note this amount also includes those facilities required by the NAS personnel who support that student.) Also the amount of facility required by the tenants can be estimated separately and is fixed for each base.
- The amount of facilities presently available provides the existing resources.
- An adjusted facilities stock can be calculated that reduces total facility stock by tenant demands.
- The facility investment cost calculations are the only relevant costs to be included in the optimizer since they are the only costs that vary with phase-to-base assignment.
- These facility investment costs can also be expressed in terms of cost per student for each phase and facility line item.

III. OVERVIEW OF THE OPTIMIZATION MODEL

INTRODUCTION

3.1 The Optimization model is a first generation model and consists of two separate submodels—the PTR Maximizer and the MCON Minimizer. It was designed specifically to assist the decision-maker in assigning the 15 different training phases to the 8 naval air stations currently used for pilot training by the Naval Air Training Command (NATRACOM).

3.2 Based on the analysis of the Static IFRS model, linear programming was selected as the technique to use in the optimization. The methodology of the Static IFRS was converted to the proper format. Next the matrices of both submodels were developed and test runs were conducted with available linear programming packages. The following paragraphs include a brief discussion of the MCON Minimizer and the PTR Maximizer submodels. Both of these submodels, as well as the reasons for selecting linear programming as the optimization technique, are discussed in detail in Volume II of this report.

MCON MINIMIZER

Purpose

3.3 The purpose of the MCON Minimizer submodel is to calculate the phase-to-base assignment that provides the minimum facility investment cost for a given PTR and MIX.

Methodology

3.4 An overview of the MCON Minimizer appears in Figure 3.1. Since linear programming models appear complex to non-mathematicians, this figure

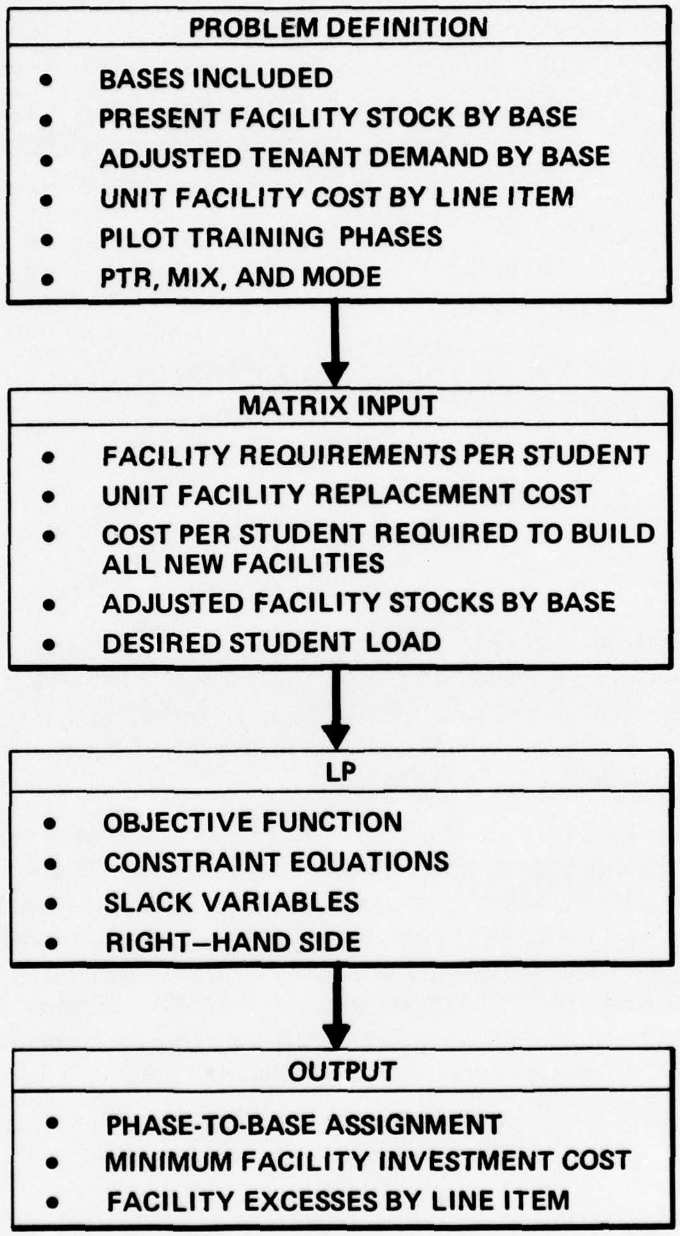

FIGURE 3.1. OVERVIEW OF MCON MINIMIZER SUBMODEL

illustrates the definition of the optimization problem, the input data requirements (i.e., matrix coefficients), where the linear programming (LP) process is required and the outputs generated.

3.5 Definition of the Minimizer Problem. Six different factors must be specified in order to define the scope of the problem, identify the variables to be considered, and specify the constraints within which the LP must operate. These factors appear in the top block of Figure 3.1 and are discussed below. Initially, the manager must specify the bases he wants to utilize in the analysis. The submodel is presently set up for the eight existing pilot training bases, but it can be set up for more or fewer bases if desired.

3.6 Next the manager must specify the total amount of each facility line item available at each base. Presently the 22 different facilities listed in Table 3.1 are included in this submodel. This facilities list is essentially the same as that in Table 2.1, except that runways are classified into three different facilities. (i.e., each length of runway is equivalent to a facility line item) and the aircraft operations building was excluded since its size is neither a function of student throughput nor tenant load. The current facility stock of these 22 facility line items can be obtained directly from the Assets Position data file of the Static IFRS model. This current facility stock should also include those facilities presently under construction.

3.7 Since non-pilot training activities also require the use of facilities at these eight bases, the amount of each facility line item required for non-pilot training use is called the adjusted tenant demand and must also be calculated. This adjusted tenant demand includes the facilities required by the tenants as well as those required by the fixed portion of the NAS personnel and the variable portion of the NAS personnel who are there to support the tenants.

3.8 Since this submodel minimizes facility investment cost, the unit cost (e.g., cost per square foot of hangar space) of each facility line item must be entered for each of the 22 facilities. These unit cost data can be obtained directly from the Static IFRS model data files.

3.9 Data that define the pilot training program must also be available. Thus, the number of training phases in the pipeline (presently there are 15) as well as the desired PTR, MIX, and MODE are required. The PTR and MIX are obtained directly from the output of the Static IFRS model.

3.10 From these factors, the scope of the problem, the variables to be considered, and the constraints are defined. These factors also form the basis for computing the coefficients for the LP matrix.

3.11 Input Data Requirements. Once the scope of the problem has been defined, these factors are used in conjunction with the Static IFRS methodology to calculate those input data shown in the second box of Figure 3.1. These are the coefficients that are entered into the LP matrix. A brief discussion of these coefficients follows:

TABLE 3.1

FACILITY LINE ITEMS

Number	Name
1	3,000 ft runway system (runway, taxiway, lighting)
2	5,000 ft runway system (runway, taxiway, lighting)
3	8,000 ft runway system (runway, taxiway, lighting)
4	Aircraft parking apron
5	Aircraft ready fuel storage
6	Underground distribution pipeline
7	Academic building
8	Aircraft maintenance hangars
9	Public works maintenance shops
10	General warehouses (covered storage)
11	Dispensary with beds
12	Administrative offices
13	Enlisted men's barracks with/without mess
14	Mess hall
15	BOQs without mess
16	Exchange
17	Enlisted men's service club
18	Electrical distribution lines
19	Water distribution lines
20	Roads
21	Auto parking aprons
22	Family housing

- Facility requirements per student—the amount of each facility line item required by one student (including the amount of facility required by the variable portion of the NAS personnel who are there because this one student is there). Since the manpower composition of each phase is different, this value must be calculated for each phase (i.e., 22 facility line items x 15 phases = 330 values).

- Unit facility replacement cost—the cost of building one unit of each facility. This is the same value used in defining the problem. In the matrix, these 22 values are used to determine the next matrix input.

- Cost per student required to build all new facilities—the cumulative cost of building the amount of each facility (i.e., 22 line items) required by one student. This value is calculated for 15 phases and 8 bases or 120 values.

- Adjusted facility stock by base—this is the amount of facility stock remaining for use by the pilot training program after all adjusted tenant demands have been satisfied. This is total stock less adjusted tenant demand with 22 facilities at 8 bases or 176 values.

- The desired student load—this is obtained directly from the PTR and consists of 15 values.

3.12 These coefficients are then entered into the LP matrix as discussed next. The value of each of these coefficients is contained in Volume II.

3.13 LP Methodology. The LP formulation consists of the following:

- An objective function which is an equation defining the objective of the problem. In this case the objective statement is composed of 296 terms representing the MCON cost for each phase by base. The programming process trys to make this MCON cost as low as possible.

- A series of equations reflecting the constraints and resource limitations of the problem (e.g., excess facilities cannot be sold to reduce cost, etc.).

- A maximum value of all constraints which is called the right-hand side (RHS); e.g., the adjusted amount of facility stock available at each base, the total student load for each phase, etc.
- A series of "slack" variables that are required to account for those resources not used; i.e., resources not used up to the limits of the right-hand side.

3.14 A diagram of these elements appears in Figure 3.2. This figure represents the resulting large matrix with coefficients representing the use of facilities required to support students as the training phases are assigned to each base. The solution of the problem is then developed by searching among different assignments of phases to bases to find that assignment that permits the desired PTR for minimum facility investment cost while not exceeding any constraints.

3.15 Initially, a feasible phase-to-base assignment (i.e., one in which no constraint is exceeded) is defined by the LP and the value of the objective function is calculated. The LP solution evolves by making changes to this initial phase-to-base assignment and recomputing the facility cost (i.e., objective function). Small changes to this assignment continue to be made until an assignment is reached where the facility investment cost cannot be decreased for the desired PTR.

3.16 Output. Once the optimal solution is reached, the manager receives the following information from this submodel:

- The number of students for each phase assigned to each base (i.e., the sum of the student load of each phase across all bases is equal to the desired student load entered).
- The minimum facility investment cost required to train the desired PTR (i.e., the total investment cost is the final value of the objective function).
- The amount of facility excesses at each base by line item.

Illustrative Example of MCON Minimizer

3.17 To illustrate the operations of the first generation MCON Minimizer, the following sample run is discussed. In this example, the question asked was, "Where should the training phases be located in order to train 2,245 students (i.e., PTR of 2,245) with the lowest possible facility investment cost?" To solve this problem, the LP matrix was set up with those coefficients discussed previously. Next the LP program was run on the computer and after approximately 800 iterations (i.e., small assignment changes), the minimum facility investment

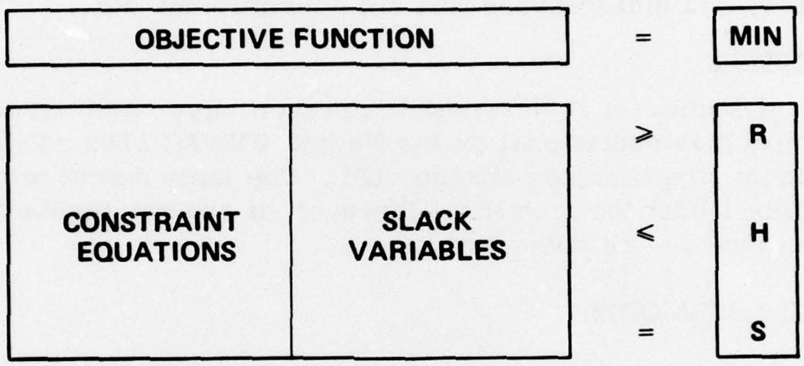

FIGURE 3.2. ELEMENTS OF THE MCON MINIMIZER

cost was calculated. The resultant phase-to-base assignment appears in Table 3.2. The total student load of each phase appears in the right-hand column and the total student load for each base appears in the bottom row. In this case, 10 phases were split into 2 or more segments while 5 phases remained totally assigned to one base. It is interesting to note that over 50% of the total student load is located at three bases (i.e., Pensacola, Whiting, and Saufley). In studying this sample output, the manager must be cognizant of the problem description previously set up. This allocation scheme is based solely on minimizing the facility investment cost at these eight bases. Furthermore, the model was run without operational policy constraints (e.g., it assumed that any phase could be located at any base, and that airspace was not constraining, etc.).

Computer Requirements

3.18 The MCON Minimizer is designed to run on a large batch processing computer. Presently it is operational on the Navy's UNIVAC 1108 computer and uses UNIVAC's linear programming package, LP1. The large matrix results in a run time of roughly 1 hour for each run. However, if several sequential runs are made, the unit run time can be decreased.

THE PTR MAXIMIZER SUBMODEL

Purpose

3.19 The purpose of the PTR Maximizer submodel is to calculate the phase-to-base assignment that provides the maximum possible PTR that can be achieved with the existing facility stock at the pilot training bases.

Methodology

3.20 An overview of the PTR Maximizer submodel appears in Figure 3.3. This figure presents a definition of the maximizer problem, the input data required, where the linear programming process is required, and the outputs generated. Volume II of this report should be consulted for a detailed discussion of this submodel.

3.21 Definition of the Maximizer Problem. The factors that must be specified in order to define the scope of the maximizer problem, identify the variables to be considered, and specify the constraints within which the LP must operate appear in the top block of Figure 3.3. Many of these factors are the same as those required to define the MCON Minimizer. The differences are:

- Only six facility line items are included in the PTR Maximizer for a single run.
- No PTR is specified in the PTR Maximizer, since a PTR is generated by this submodel.
- Unit facility costs by line item are not required in this submodel, since cost is not considered.

TABLE 3.2

MCON MINIMIZER—STUDENT LOAD BY
BASE AND PHASE*

Phase	Base								Total Phase
	Chase	Corpus	Ellyson	Kingsville	Meridian	Pensacola	Saufley	Whiting	
1. AOC School			36			140	207		383
2. Envir Indoc							84		84
3. Primary			255				94		349
4. Basic Jet A		14				198			212
5. Basic Jet B		136							136
6. Basic Jet CQ	99								99
7. Adv Jet TF	86				91				177
8. Adv Jet TA		74		103					177
9. Basic Prop							81	364	445
10. Basic Prop CQ						51		30	81
11. Adv Prop		91		136	88	6			321
12. Basic Helo						117		60	177
13. Pre-Helo								45	45
14. Helo Prim.		36							36
15. Helo Adv		34						37	71
Total Base	185	335	291	239	179	512	466	536	2,793

* PTR = 2,245

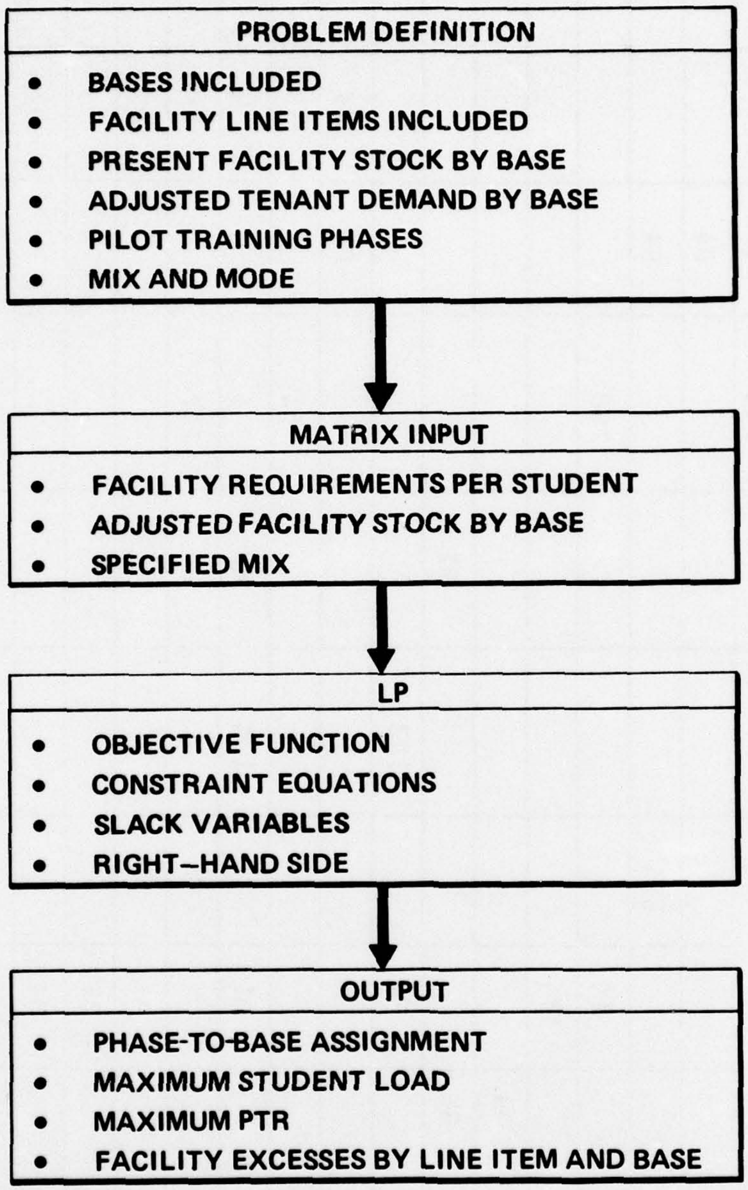

FIGURE 3.3. OVERVIEW OF PTR MAXIMIZER SUBMODEL

3.22 First, the manager must specify which bases he wants to utilize. Next, he selects the facility line items to be included in the PTR Maximizer run. These are the facilities that determine the PTR. He selects 6 facilities from the 22 facilities that were previously listed in Table 3.1. For these six facilities, the present stock by base and the adjusted tenant demand must be known. The number of training phases, the MIX, and MODE must also be known. These data specify the proportion of students who must be in each phase to graduate a PTR with the proper MIX. These factors that define the scope of the problem, the constraints, and variables included are also used as the basis for calculating coefficients for the LP matrix.

3.23 Input Data Requirements. The coefficients that are entered into the LP which were calculated with the above factors and the Static IFRS methodology appear in the second block of Figure 3.3.

- Facility requirement per student—this is the same as discussed in the MCON Minimizer submodel; however, only 6 facility line items are included for 1 run in this submodel (i.e., 6 facility line items x 15 phases or 90 values).
- Adjusted facility stock by base—this was also discussed with the MCON Minimizer; however, with 6 facilities, there are only 48 values in this submodel (6 x 8 = 48)
- Specified MIX—this is the proportion of the number of students who must be in each phase (i.e., 15 values).

These coefficients are then entered into the LP matrix.

3.24 LP Methodology. This LP formulation is similar to the MCON Minimizer formulation as shown in Figure 3.3 . It consists of the following:

- An objective function which is an equation that defines the objective of the problem. In this submodel, the objective function is composed of a set of variables representing student load for each training phase by base, and the LP trys to make this student load as large as possible. In this submodel the objective function equals a maximum whereas previously it equaled a minimum.
- A series of equations reflecting the constraints and resource limitations of the problem, e.g., the proportion of students in each phase must always result in a PTR with the proper MIX.

- A maximum value of all constraints which is called the right-hand side; e.g., the number of runways at a base is 4 or less.
- A series of "slack" variables required to account for those resources that are not used; i.e., resources not used up to the limit of the right-hand side or the excess facilities.

This problem is represented by a large matrix with coefficients representing the use of facilities required to support students as the training phases are assigned to each base. The LP solution evolves in a manner similar to that of the MCON Minimizer solution. It evolves by assigning phases to bases, computing facility excesses, making a small change in assignment, recomputing excess, until an assignment is reached where throughput (PTR) cannot be increased.

3.25 Output. The manager receives the following information from the PTR Maximizer.

- The maximum number of students for each phase assigned to each base
- The amount of each facility line item not used (i.e., excesses) by either the tenants or pilot training program.

The sum of the student loads of each phase across all bases can then be directly related to the throughput and the resulting PTR. The MIX is as initially specified. The manager knows the amount of excess facilities at each base and can utilize them as necessary for other purposes.

Illustrative Example

3.26 The two following sample runs illustrate the operation of the first generation PTR Maximizer. Each run includes different facility line items.

3.27 Facility Group I Example. In this example, the question asked was: "How many students can be trained using all 8 bases and the present 15-phase pipeline based on the availability of the following facilities—BOQs, enlisted men's barracks, mess halls, family housing, administrative offices, and warehouses?"

3.28 The LP matrix was set up to reflect the per student facility requirements and adjusted facility stocks for these six facility line items and the present MIX. Next the computer program was run and after 120 iterations (operations of the algorithm), the maximum student loads assigned to each base were calculated as shown in Table 3.3. The total student load of each phase appears in the right-hand column and the total student load for each base appears in the bottom row. Note that in five instances, the model split the training phases. The Advanced Jet TA phase, was split into three components. The resultant student loads provide a PTR of 1,970 pilots as shown at the bottom of Table 3.3. It

TABLE 3.3

PTR MAXIMIZER—STUDENT LOAD BY BASE AND PHASE,
FACILITY GROUP I—PRESENT PIPELINE*

Phase	Base								Total Phase
	Chase	Corpus	Ellyson	Kingsville	Meridian	Pensacola	Saufley	Whiting	
1. AOC School						280			280
2. Envir Indoc						74			74
3. Primary						307			307
4. Basic Jet A		187							187
5. Basic Jet B			25					95	118
6. Basic Jet CQ	87								87
7. Adv Jet TF	79				76				155
8. Adv Jet TA					86		42	28	156
9. Basic Prop			34	356					390
10. Basic Prop CQ		71							71
11. Adv Prop	19	263							282
12. Basic Helo		156							156
13. Pre-Helo		16				23			39
14. Helo Prim.						32			32
15. Helo Adv								62	62
Total Base	185	693	59	356	162	716	42	183	2,396

* Maximum PTR = 1,970 $\begin{cases} \text{755 Jet} \\ \text{825 Prop} \\ \text{390 Helo} \end{cases}$

should be remembered that this allocation scheme is based solely on the availability of the six different facilities which the manager wanted to use in this sample run. Furthermore, the model was run without operational policy constraints (e.g., it assumed that any phase could be located at any base). Table 3.4 contains a listing of the excess facilities remaining at each base after this allocation. Facilities that have zero excess are those that limited the PTR. Thus for NAS Corpus Christi, both enlisted men's barracks and family housing were constraining while administrative offices appeared as a constraint at NAS Kingsville.

3.29 In all probability, the manager would want to make another computer run excluding administrative offices since this facility probably does not actually limit the pilot training program. In fact, for the pilot training program he probably should make runs based on aircraft-related facilities.

TABLE 3.4

PTR MAXIMIZER—EXCESS FACILITIES,
FACILITY GROUP I

Base	Facility*					
	Warehouse	Admin Office	EM** Barracks	Mess Halls	BOQs	Family Housing
Chase	4,552	13,804	565	23,721	29	0
Corpus	863,885	86,124	0	4,024	100	0
Ellyson	14,543	0	321	8,327	146	537
King	83,785	0	549	18,644	12	114
Meridian	18,896	10,081	335	7,763	337	0
Pensacola	583,224	82,532	563	0	1,177	92
Saufley	5,039	0	358	7,173	537	403
Whiting	7,754	0	366	23,585	346	532

* See Table 2.1 for units of measure.
** Enlisted men.

3.30 <u>Facility Group II Example.</u> This second example illustrates the use of the PTR Maximizer based on the following aircraft-related facilities:

- 3,000 ft runways
- 5,000 ft runways
- 8,000 ft runways
- Aircraft parking aprons

- Maintenance hangars
- Enlisted men's barracks.

Based on the availability of these facilities, the maximum PTR is 3,360 or almost 1,400 more than with facility group I. The resulting student loads and phase-to-base assignments appear in Table 3.5.

Computer Requirements

3.31 The PTR Maximizer is designed to run on a relatively small batch processing computer. Presently it is operational on ORI's CDC 3100 machine and takes approximately 7 minutes per run.

TABLE 3.5

PTR MAXIMIZER STUDENT LOAD BY BASE AND PHASE
FACILITY GROUP II—PRESENT PIPELINE*

Phase	Base								Total Phase
	Chase	Corpus	Ellyson	Kingsville	Meridian	Pensacola.	Saufley	Whiting	
1. AOC School			455						455
2. Envir Indoc			120						120
3. Primary		234					77	188	499
4. Basic Jet A					159			145	304
5. Basic Jet B							17	178	195
6. Basic Jet CQ					137		4		141
7. Adv Jet TF	214	19				20			253
8. Adv Jet TA		103		96	54				253
9. Basic Prop	95	482					60		637
10. Basic Prop CQ							116		116
11. Adv Prop				232	61	166			459
12. Basic Helo	89					165			254
13. Pre-Helo							64		64
14. Helo Prim.		28						24	52
15. Helo Adv		11	91						102
Total Base	398	877	666	328	411	351	338	535	3,904

* Maximum PTR = 3,360 $\begin{cases} \text{1,250 Jet} \\ \text{1,470 Prop} \\ \text{640 Helo} \end{cases}$

IV. CONCLUSIONS AND RECOMMENDATIONS

4.1 The development of an optimization model for the IFRS study is feasible and the development of two prototype submodels confirms this feasibility. These submodels provide the facilities manager with a powerful analytic tool that if used properly will greatly enhance his management capabilities. In fact even a quick review of the various coefficients required points out many interesting facts on the training program.

LIMITATIONS

4.2 This study was an initial attempt to determine if an optimization type model could be developed with the data and methodology presently available. Even though the scope of the study limited the data sources to the Static IFRS model, these two prototype submodels are technically correct and accurate. However, these submodels do not consider all factors associated with the pilot training program (e.g., travel cost, feasibility of splitting phases, etc.) and thus do not provide a truly optimum training program. Unfortunately, the model is somewhat limited by the assumption of continuous runways. This problem could be overcome by the development of an integer linear program to handle runways.

RECOMMENDATIONS

4.3 It is recommended that additional runs be made on these two submodels based on several alternative problems. For instance, the MCON Minimizer might be run for seven bases and a completely new syllabus. These new runs would provide NAVFAC with a better understanding of the capabilities of these submodels.

4.4 Second, it is recommended that a time-share computer program that calculates the multitude of coefficients be developed. Thus, when the pilot training program changes, these new coefficients could be readily available for making new runs on the Optimization model.

4.5 Third, it is recommended that a similar optimization model be developed for the fleet NAS at a later date. It is believed that the use of these submodels may prove more useful to the fleet NASs since they change composition more often.